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INVENTORY

Ohio State Univ., Columbus
ElectroScience Lab.

ESL-3973-2

DOCUMENT IDENTIFICATION

Final, Dtd Jan. 1976

Contract No. N62269-74-C-0788

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# ON-AIRCRAFT ANTENNAS

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AD A088940

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FINAL REPORT 3973-2

January 1976

Naval Air Development Center
Warminster, Pennsylvania 18974

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)

ON-AIRCRAFT ANTENNAS

5. TYPE OF REPORT & PERIOD COVERED

Final Report

6. PERFORMING ORG. REPORT NUMBER

ESL 3973-2

7. AUTHOR(s)

P. H. Pathak

8. CONTRACT OR GRANT NUMBER(s)

N62269-74-C-0788

9. PERFORMING ORGANIZATION NAME AND ADDRESS

The Ohio State University ElectoScience Laboratory
Department of Electrical Engineering
Columbus, Ohio 43212

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

Naval Air Development Center
Warminster, Pennsylvania 18974

12. REPORT DATE

January 1976

13. NUMBER OF PAGES

21

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)

Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

**DISTRIBUTION STATEMENT A**
**Approved for public release; Distribution Unlimited**

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

theoretical aircraft models
off-fuselage aircraft antennas
GTD
transition region solution
equivalent current solution
elliptic cylinder configuration
elliptic disc configuration
radiation patterns

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This investigation is concerned with the problem of predicting the performance of aircraft antennas which are mounted off the aircraft fuselage. In particular, the fuselage plays a very significant role in affecting the patterns (and hence the system performance) of wing or tail mounted aircraft antennas. In the present study, the aircraft fuselage is modeled theoretically by a finite length elliptic cylinder which is a satisfactory representation of a great majority

of practical aircraft fuselage configurations. Hence, the study is directed toward predicting the field patterns of electric or magnetic current moments which radiate in the near zone of a finite length, perfectly-conducting elliptic cylinder. The method of analysis is based on the GTD (ray-optical) technique, and it's relevant modifications which are required in the transition regions adjacent to shadow boundaries and caustics wherein the GTD fails. The present GTD method of analysis leads to simple and accurate results; it is thus an attractive alternative to costly and time-consuming aircraft model measurements. Efficient computer codes are generated for numerical processing of the analytical results. Additional work is proposed on a problem which has arisen in the course of the present study and which merits further attention.

CONTENTS

## I. INTRODUCTION

It is well known that the performance of on-aircraft antennas is very significantly affected by the rest of the aircraft structure. In most cases, it is the antenna pattern which is affected. Consequently, in the design of antennas for airborne applications, it is extremely desirable to be able to predict in advance, the structural effects on the patterns of these antennas. Previous work performed on this subject at the ElectroScience Laboratory was directed toward studying the effects of aircraft wings and fuselage on the patterns of "fuselage-mounted" antennas [1-5]. This problem was successfully analyzed via Keller's geometrical theory of diffraction (GTD) [6], together with the more accurate and general ray diffraction coefficients developed at The Ohio State University [7,8].

The present study extends this earlier work to analyze the radiation from antennas which are mounted off the fuselage, such as from wing or tail mounted antennas. In these cases, the aircraft fuselage significantly affects the radiation pattern characteristics, and hence the system performance. The GTD method of analysis is also employed in the present study dealing with off-fuselage antennas; furthermore, additional extensions and modifications of the GTD are carried out in this study to describe the fields scattered or diffracted within the transition regions adjacent to the shadow boundaries and caustics of the GTD ray systems. These extensions and modifications to the GTD are required since the GTD is not valid at shadow boundaries and caustics.

In the present investigation, the aircraft fuselage is modelled by a finite length, perfectly-conducting elliptic cylinder; the elliptic cylinder geometry allows for variations in the fuselage cross-sections so as to provide a best fit for a variety of actual aircraft fuselage shapes. The source which excites the finite length elliptic cylinder is chosen to be either an electric or magnetic current moment which is located in the near zone of the cylinder, but the cylinder itself could be in the far zone of the source. This choice of source distribution allows for a variety of antenna types to be incorporated, since the fields of an arbitrary source may be constructed via a superposition of a set of quantized, appropriately oriented and weighted electric and/or magnetic current moments which represent the equivalent sources in the aperture corresponding to an actual antenna. The fields of the source in the presence of the elliptic cylinder are then analyzed via GTD.

The GTD ray analysis imparts a simple physical picture for the scattered and diffracted fields in terms of rays which propagate from the source to the field point after reflecting and/or diffracting from certain localized portions of the scatterer (which is a finite length elliptic cylinder in the present case). Thus, the computational effort for numerically processing the analytical results is substantially reduced using this approach to obtain the far field patterns.

The physically illuminating GTD method is not only efficient, but due to its local ray representation for the scattered and diffracted fields, it allows for the incorporation of other scattering effects besides those due to the fuselage, if so desired in the future. Although the GTD is an asymptotic high frequency method, it works quite accurately even for moderately high frequencies. Typically, the GTD can handle structures whose electrical dimensions are all greater than approximately a wavelength. Even this requirement can be relaxed in certain cases.

## II. TECHNICAL APPROACH

The analysis of the radiation from an electric or magnetic current moment in the presence of a finite length, perfectly-conducting elliptic cylinder whose configuration is illustrated in Fig. 1 is carried out in several steps. First, the scattering by an infinitely long elliptic cylinder is treated; subsequently, the scattering by a planar ellipitic disc is considered. The latter configuration corresponds to the end caps of the finite length elliptic cylinder; i.e., of the truncated elliptic cylinder of Fig. 1. These cases are treated separately since the scattering mechanisms may be assumed to be distinct and essentially uncoupled. In each case, the GTD analysis is followed by the generation of appropriate and efficient computer codes for numerical processing of the results developed in the analysis. The final phase of the solution involves the proper interfacing of these computer codes into a single one for treating the complete finite length elliptic cylinder geometry. These steps will be briefly reviewed.

### A. Infinite Elliptic Cylinder Analysis

In the infinite elliptic cylinder part of the analysis, the scattering and diffraction mechanisms are represented in terms of the usual geometrical optics incident and reflected rays together with the surface diffracted rays (creeping rays) of Keller [6]. The pertinent diffraction and reflection coefficients for this problem are available so that the analysis in terms of these rays presents no difficulty away from the shadow boundaries (caused by grazing incidence on the cylinder).

At and near the shadow boundaries, the GTD ray method fails; it therefore requires modification in the transition regions adjacent to shadow boundaries. This modification of the GTD is carried out, and a uniform asymptotic solution is developed such that it remains valid in the transition regions. This solution is constructed by asymptotically solving the canonical problem of plane wave scattering by a perfectly-conducting circular cylinder; the results of this solution are later extended to the elliptic or variable curvature cylinders in a systematic fashion via ray-optical considerations.

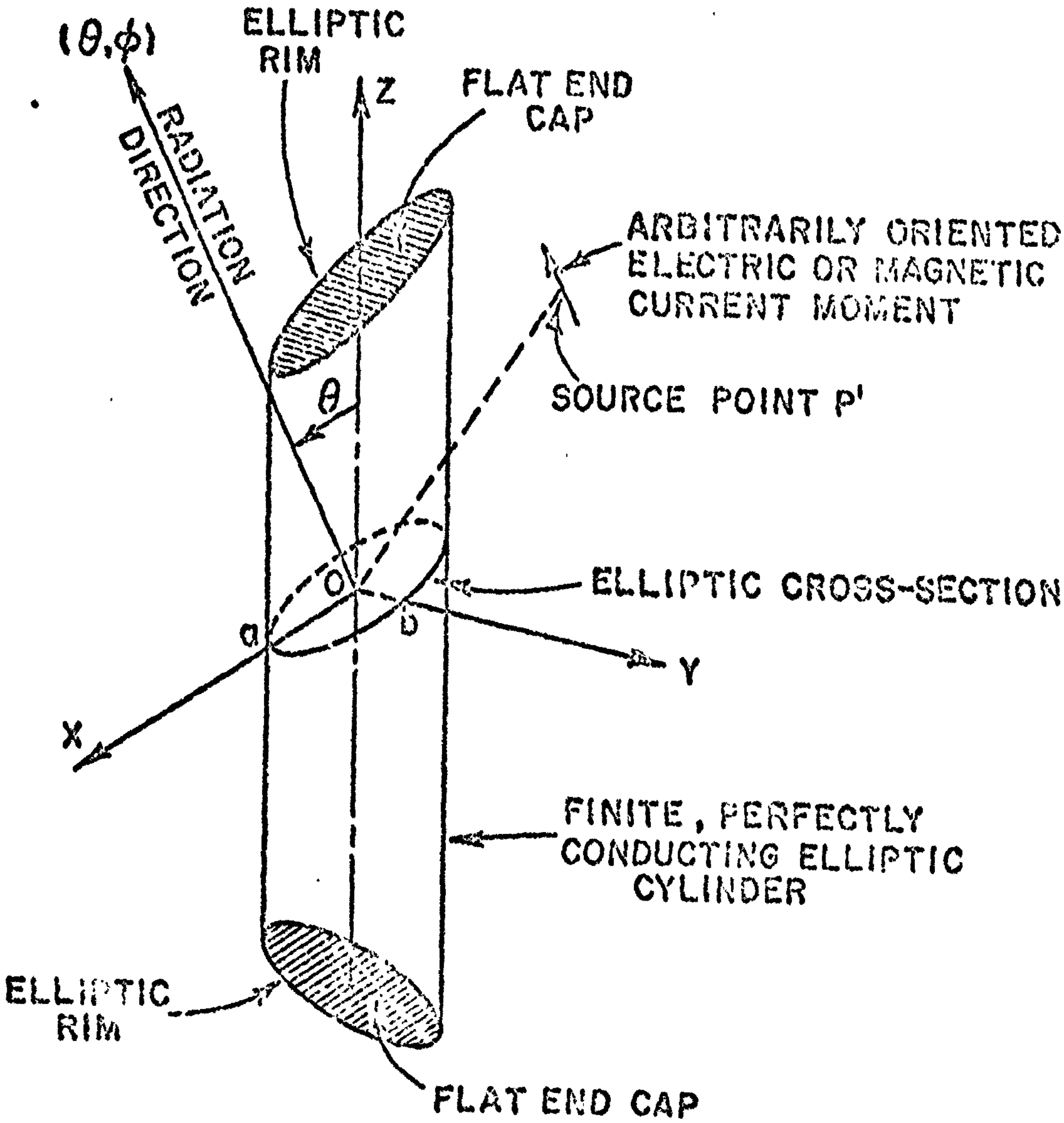



Fig. 1. A current moment illuminating a finite elliptic cylinder.

This uniform result yields a finite, continuous variation for the total field across the shadow boundaries (in contrast to the GTD solution which is discontinuous there) within the transition regions; exterior to the transition regions it reduces to the usual GTD solution in terms of geometrical optics (incident and reflected) and surface diffracted rays for the lit and shadow zones, respectively. The accuracy of this result is confirmed by numerical comparison with the results obtained via an exact eigenfunction solution for the circular cylinder case, and with an independent moment method (MM) solution for the elliptical cylinder case. The results of this comparison are indicated in Figs. 2 - 4 for circular and elliptic cylinders excited by line and point sources.

A considerable amount of effort was expended in developing efficient-computer codes for numerical processing of these GTD-transition analysis results; in particular, the computer subroutines for locating points of surface reflection and diffraction, and the surface ray paths on the cylinder were developed.

## B. Scattering by a Planar Elliptic Disc

The problem of the scattering by a planar, perfectly-conducting elliptic disc is essential to the analysis of the scattering by the end caps of the finite length elliptic cylinder (of Fig. 1). Besides the incident and reflected rays of geometrical optics, there are diffracted rays which are produced via the diffraction of the incident ray field by the edges of the disc. Since the edge of the disc is elliptically shaped, there are, in general, four unique points of edge diffraction wherefrom diffracted rays emanate to the field point.

These points of edge diffraction are ascertained numerically via a computer subroutine which is based on the law of edge diffraction to deduce these points. Furthermore, these points of edge diffraction move around the elliptic rim with change of field point and/or change in source location. As a result, there are certain locations of the field point (for a given source point) in whose vicinity three of the four diffracted rays tend to merge into a single ray, i.e., two points of diffraction tend to suddenly vanish for this case.

The latter behavior may be viewed as a pseudo-caustic effect since in the absence of proper care in treating the disappearance of two of the four points, an erroneously large result is obtained resulting from the merger of three of the four points of diffraction into a single point; in the proper sense, this effect must be viewed as a disappearance of two points of diffraction rather than a merger of three points of diffraction. The GTD fails to describe the transition from a four-diffracted ray to a two ray contribution and hence needs modification. This modification has been achieved in the present study through the use of equivalent rim currents which indirectly

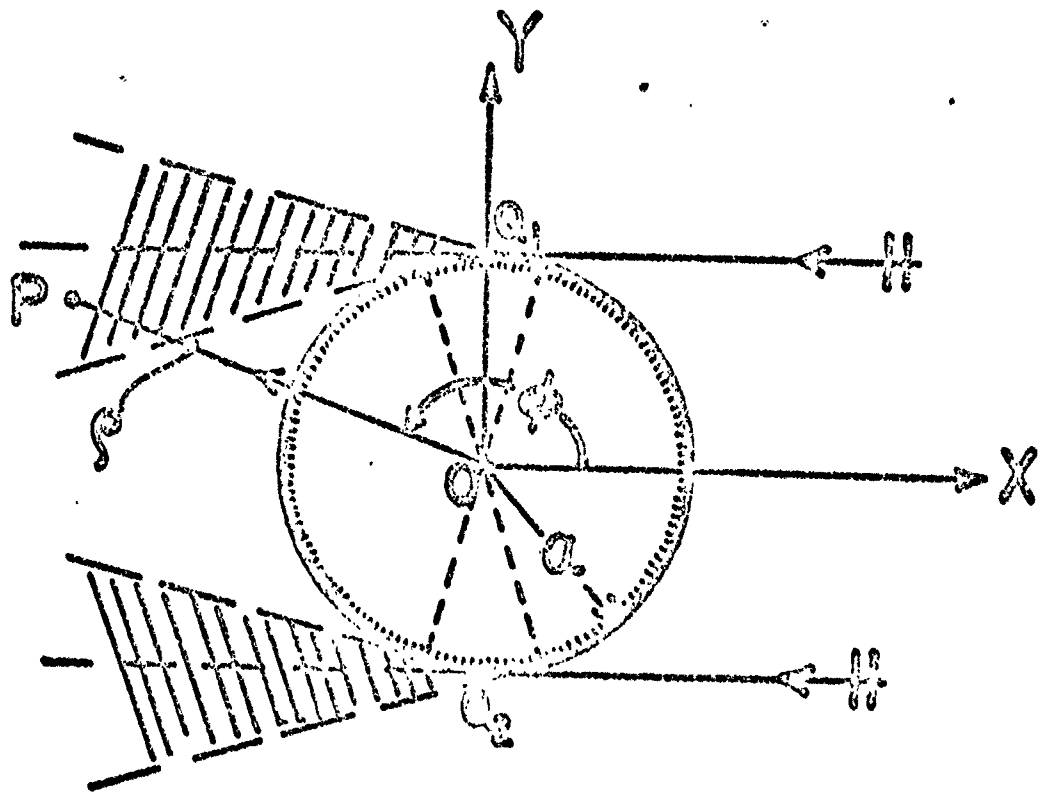



Fig. 2(a). Circular cylinder illuminated by a plane wave incident along the negative x direction. The shaded areas correspond to the transition region associated with the shadow boundaries.

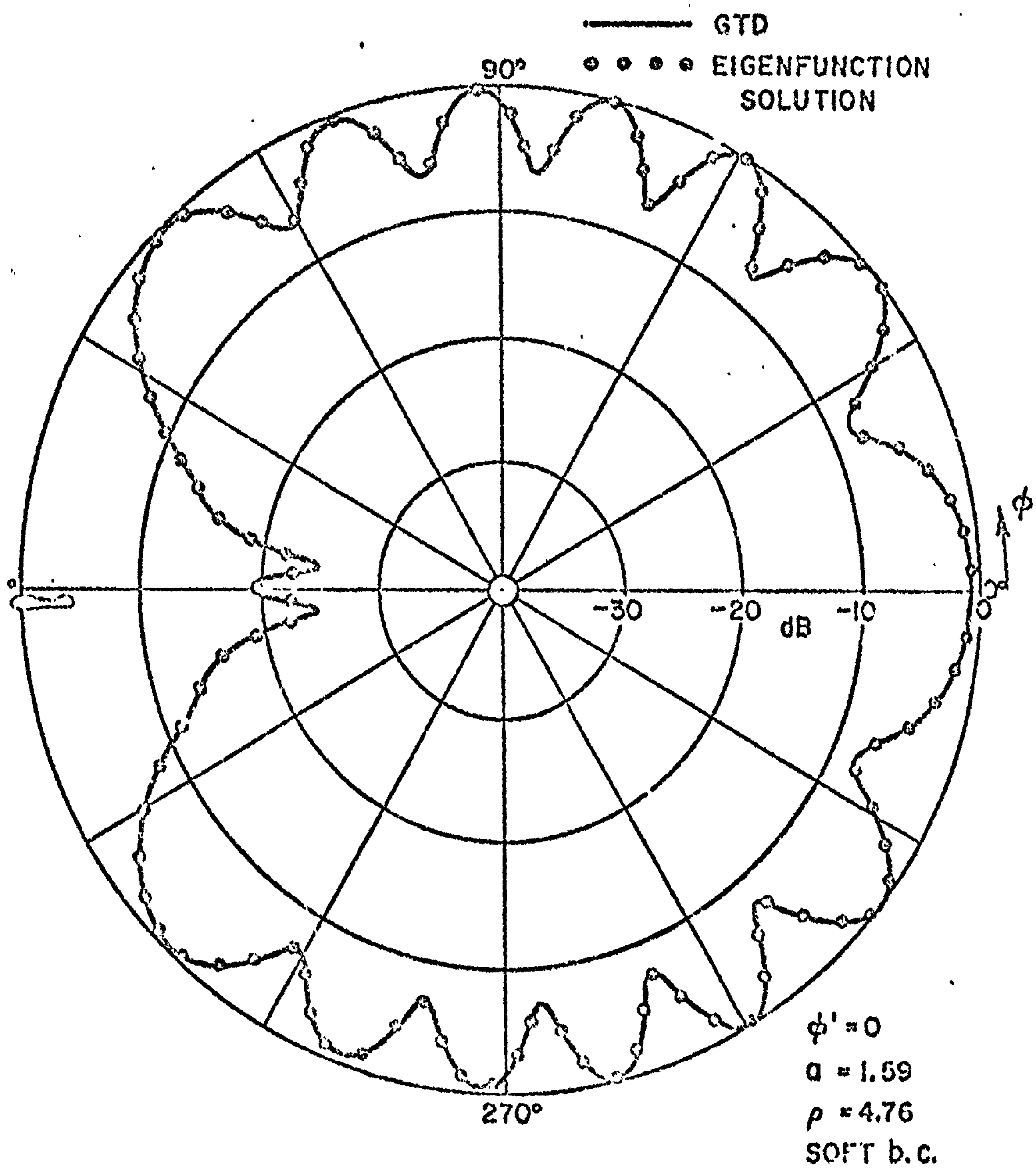



Fig. 2(b). Total field surrounding the cylinder of Fig. 2(a). Here, GTD implies the GTD + transition solution. The incident electric field is $\hat{z}$-directed (acoustic soft case).

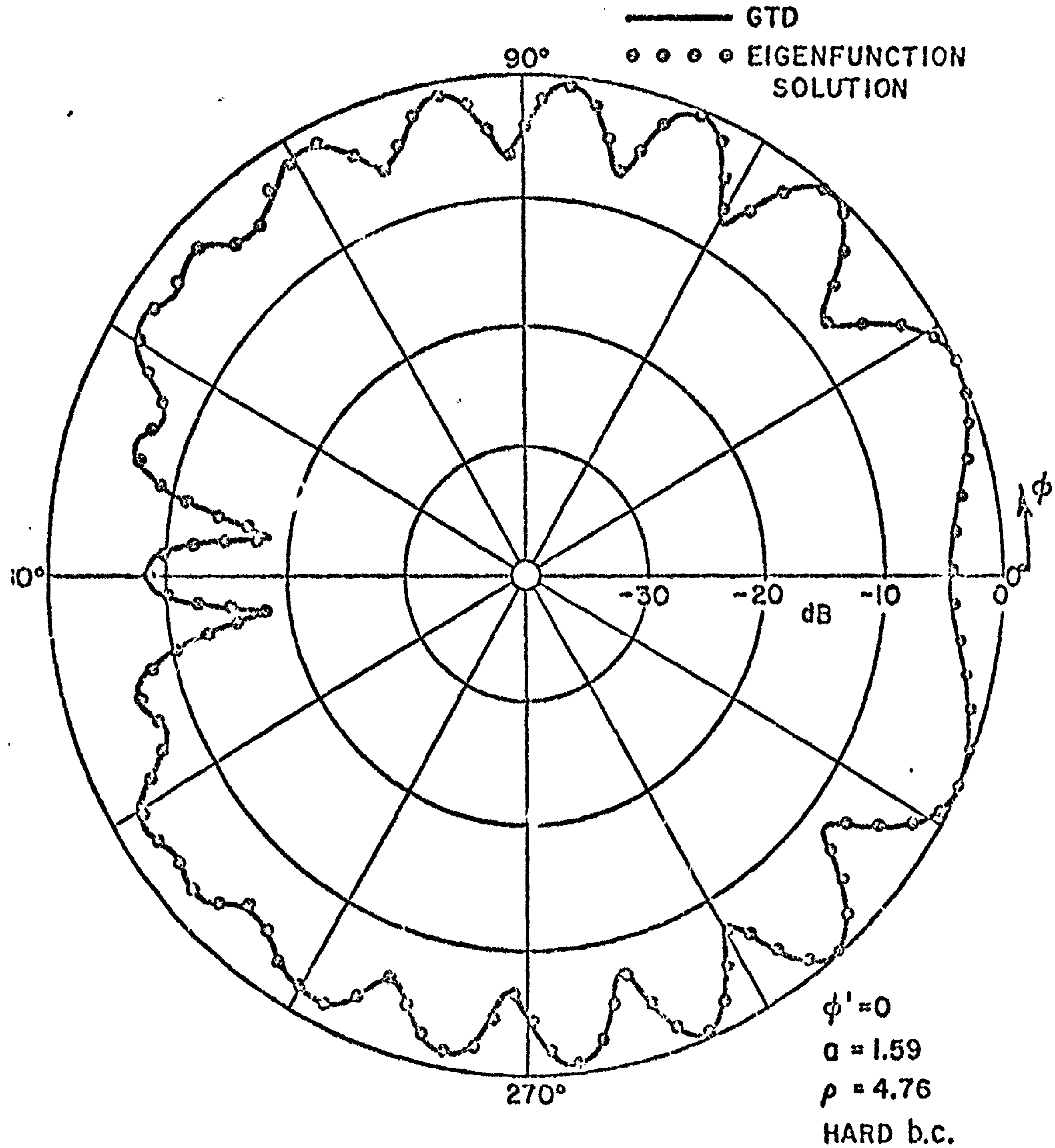
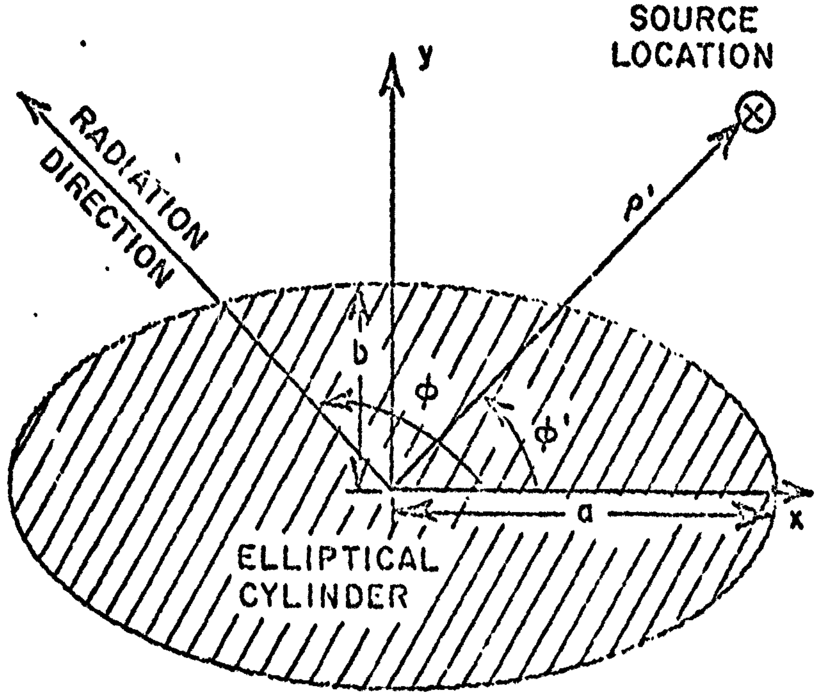



Fig. 2(c). Total field surrounding the cylinder of Fig. 2(a). Here, GTD implies the GTD + transition solution. The incident magnetic field is $\hat{z}$-directed (acoustic hard case).




$a = 2\lambda, \ b = 1\lambda, \ \rho' = 4\lambda$

Fig. 3(a). Elliptic cylinder configuration excited by a 2-D magnetic line source.

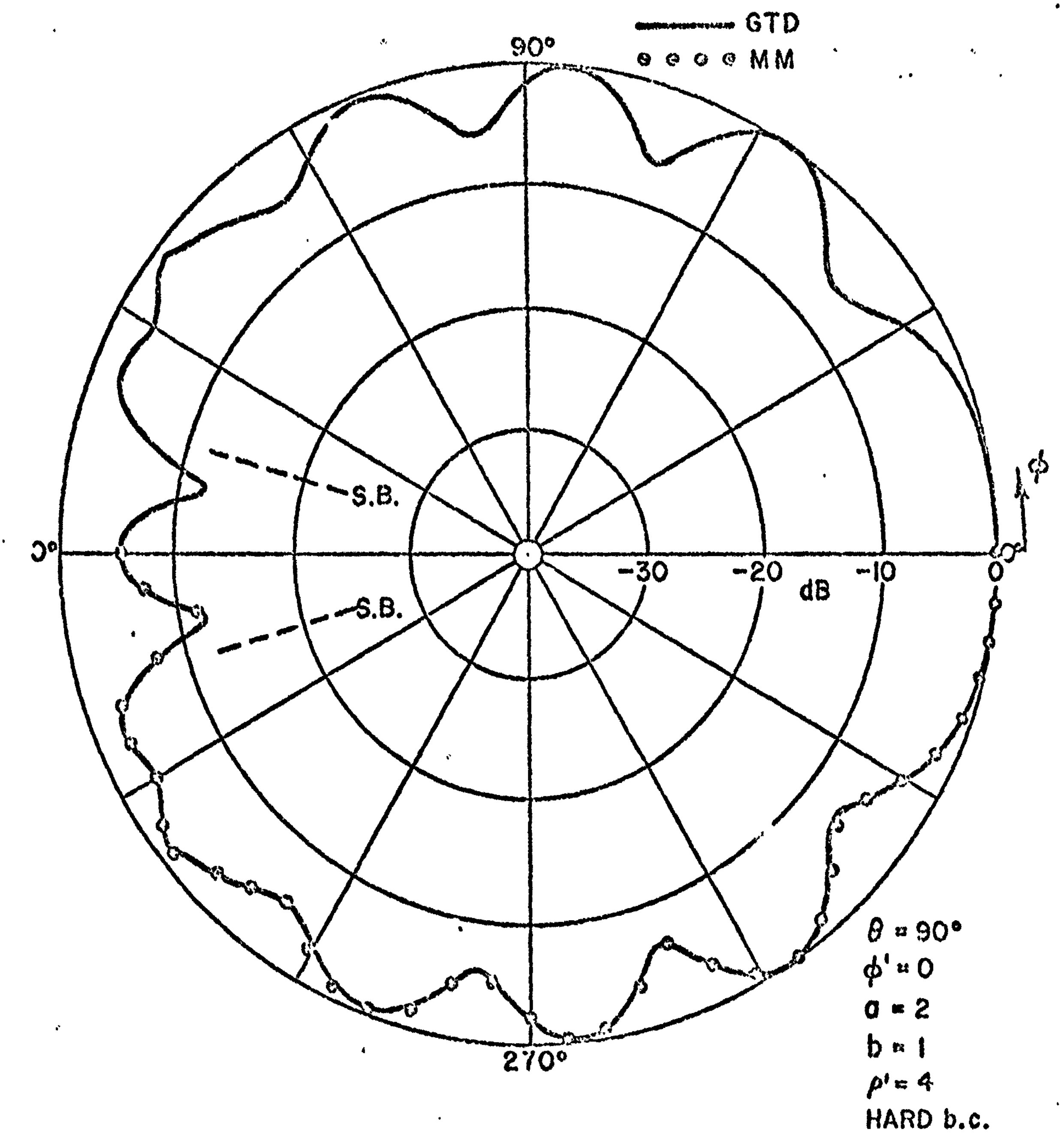



Fig. 3(b). Total far-field surrounding the elliptic cylinder of Fig. 3(a). Here, GTD implies GTD + transition solution.

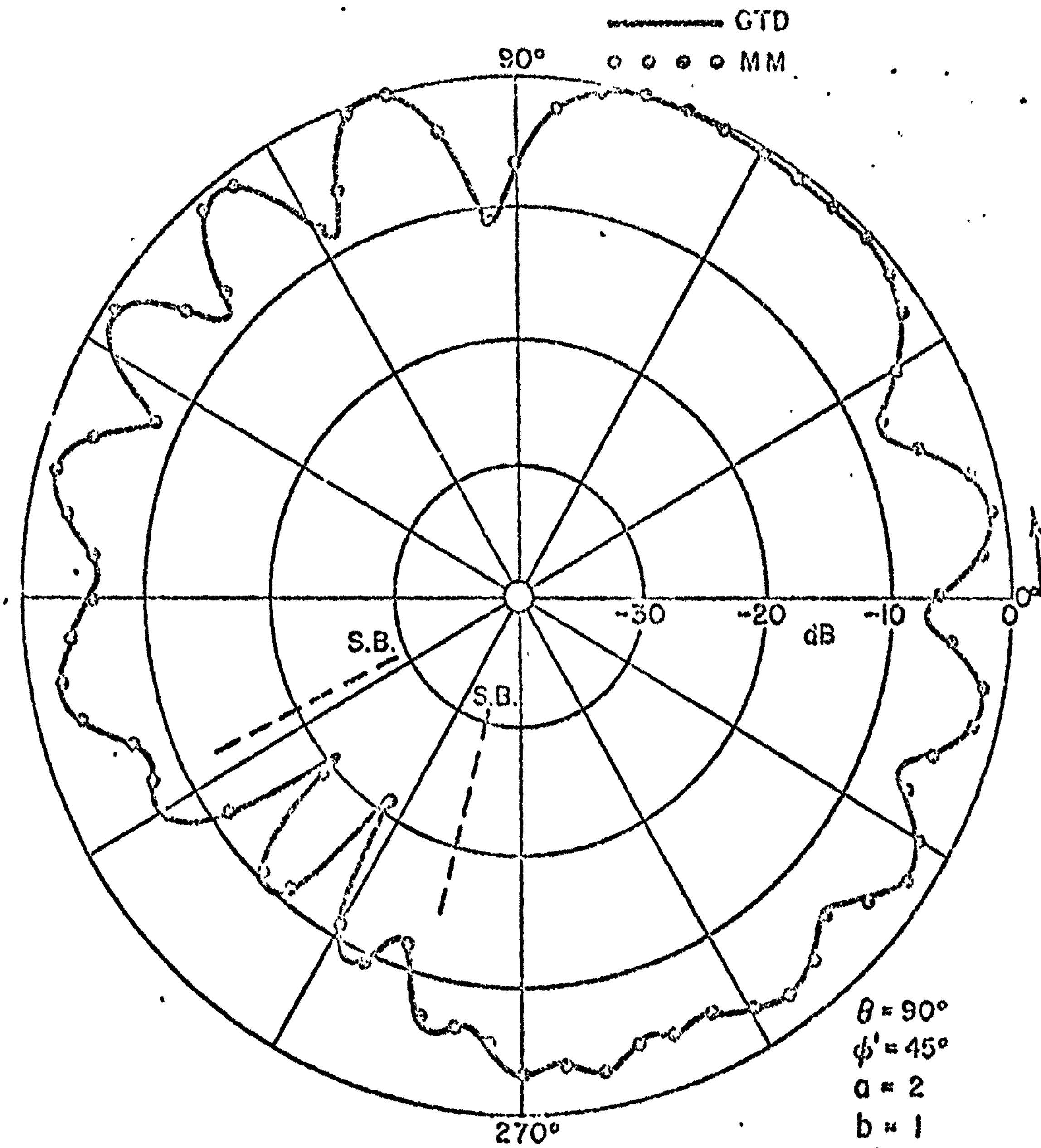



Fig. 3(c). Total far-field surrounding the elliptic cylinder of Fig. 3(a). Here, GTD implies GTD + transition solution.

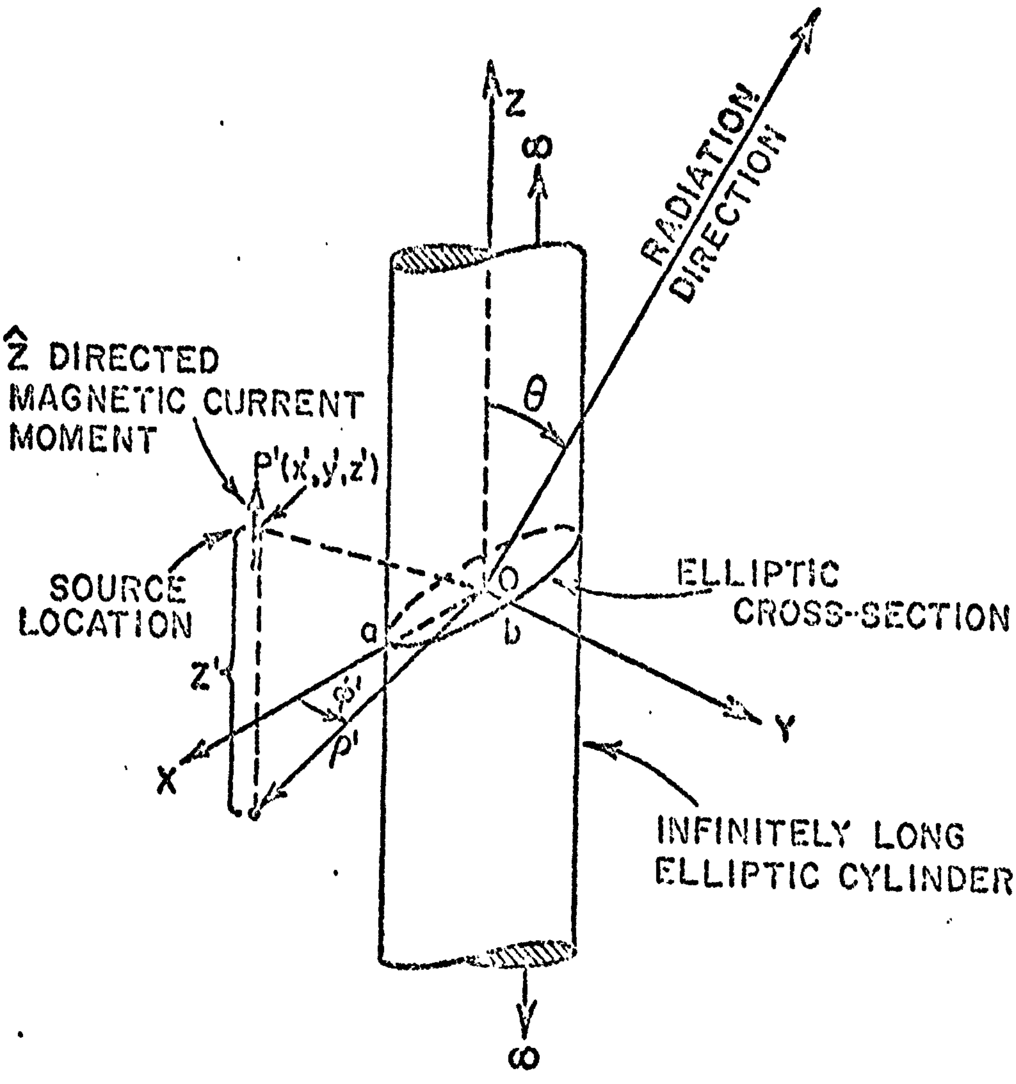



Fig. 4(a). 3-D scattering configuration involving an infinitely long elliptic cylinder.

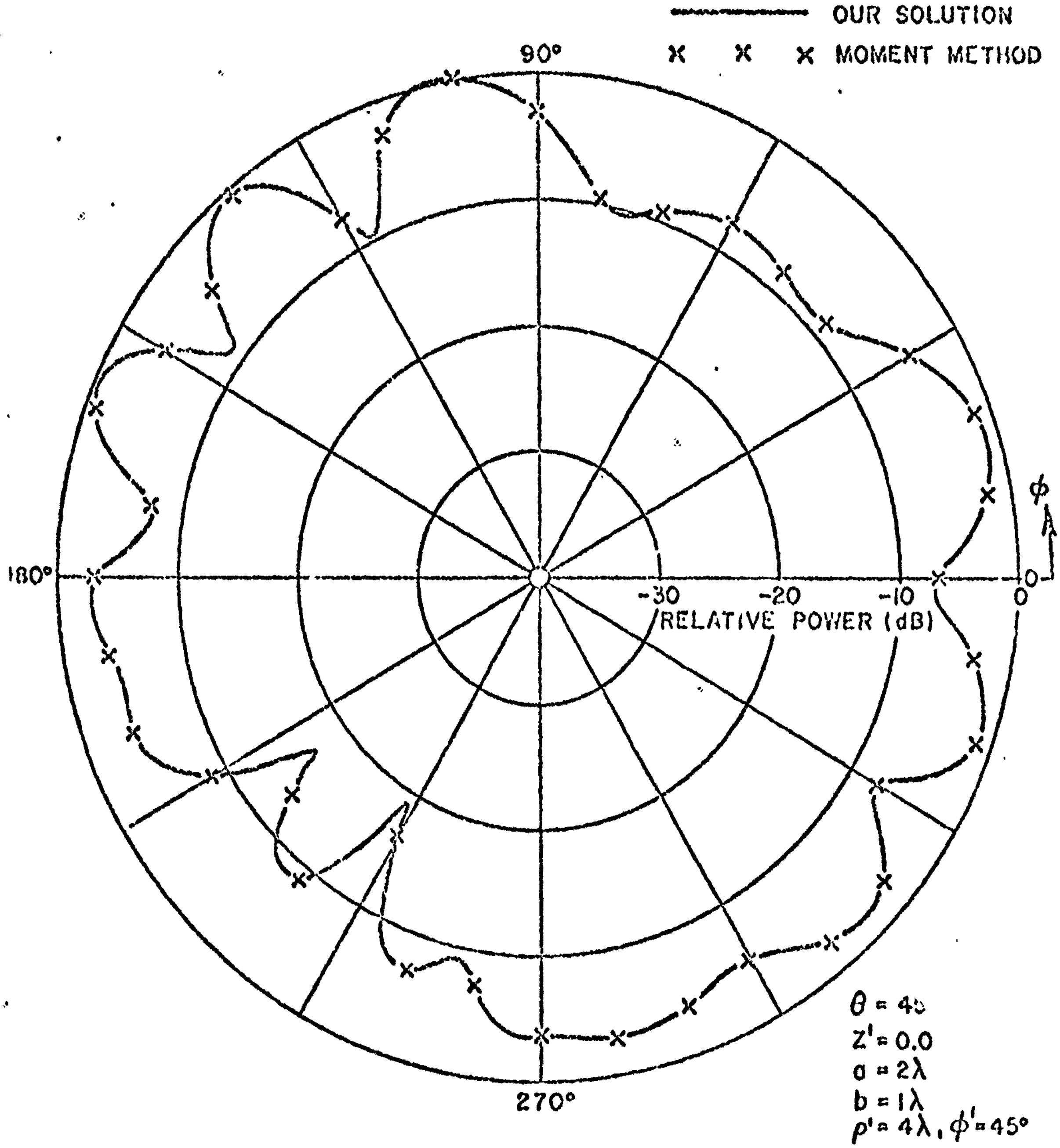



Fig. 4(b). Conical scan radiation pattern for the 3-D scattering configuration of Fig. 4(a). The pattern of the $\hat{\phi}$-component of the electric field is shown.

employ the GTD edge diffraction coefficients. These equivalent edge currents are then incorporated in the radiation integrals which yield a smooth behavior for the field across these pseudo-caustic regions.

Figures 5 - 6 indicate the patterns of current moments which radiate in the presence of elliptic discs. Some of these results are compared against corresponding measured values. Indeed, the agreement between the calculated and measured patterns is very good. Some slight differences between the calculated and measured patterns are due to the fact that an infinitesimal current moment or a point source representation is used to illuminate the disc; whereas, a finite length (but electrically short antenna) is employed in measurements.

One of the major problems in this phase of the analysis was to generate an accurate and a high-speed computer code to locate the points of edge diffraction; consequently, some new computational procedures evolved in tackling this problem. Presently, the new procedure is much faster than the older (but also quite efficient) computational method for locating the edge diffraction and surface reflection points.

Another computational difficulty occurred in switching from the equivalent current to the four point GTD solution which is valid outside the pseudo-caustic transition region; presently, this problem has been overcome in an empirical fashion which offers the necessary information for the switching decision to be made in the appropriate computer subroutine.

At the time of this writing, the computer codes for the analysis in parts A and B above have been combined and will be ready for delivery shortly.

## III. CONCLUSIONS

It is seen from this study of the scattering by a finite length, elliptic cylinder (illuminated by a near-zone source) that one indeed generates a pattern which has great variations in the illuminated regions of the source-cylinder confiruation, and a sudden drop in the pattern level within the regions deeply shadowed by the cylinder. The pattern variations in the illuminated region occur mainly from the interference of the fields of the incident and reflected rays.

The much lower pattern levels in the deep shadow region are accounted for by the absence of the geometrical optics incident and reflected rays in this region; the fields in the shadow region are entirely accounted for by the surface diffracted rays which constitute a weaker effect in comparsion with the geometrical optics fields in the illuminated region. Of course, diffraction effects are extremely important within transition regions adjacent to the shadow boundaries; furthermore,

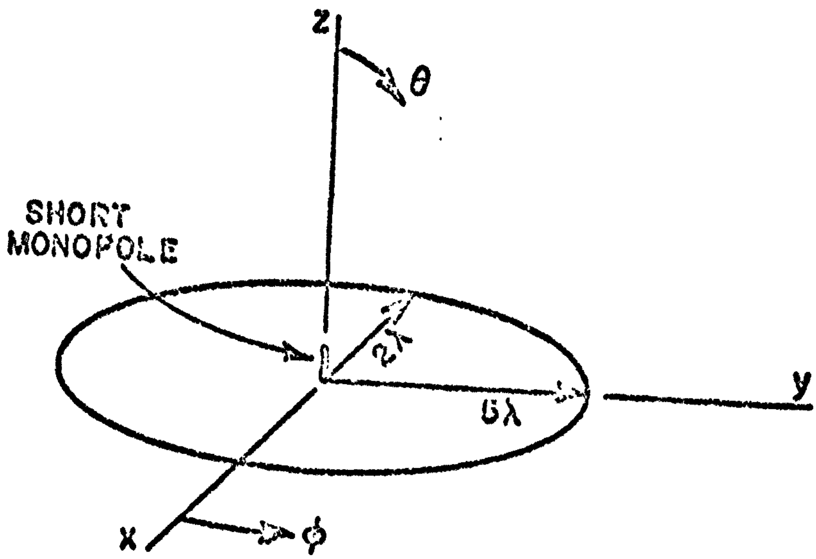



Fig. 5(a). Monopole on an elliptic disc.

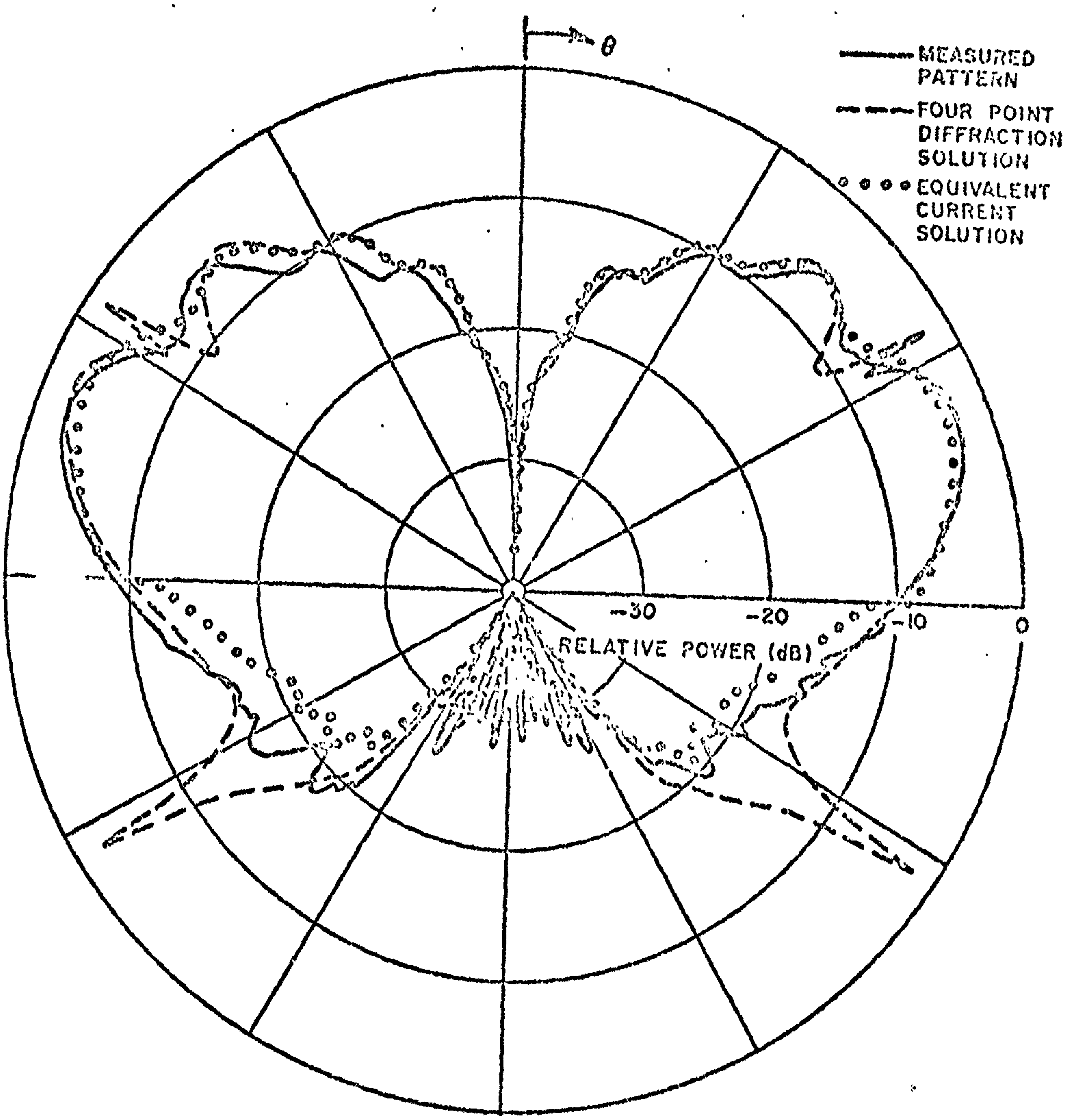



Fig. 5(b). E-theta radiation pattern in the y-z plane for the configuration in Fig. 5(a).

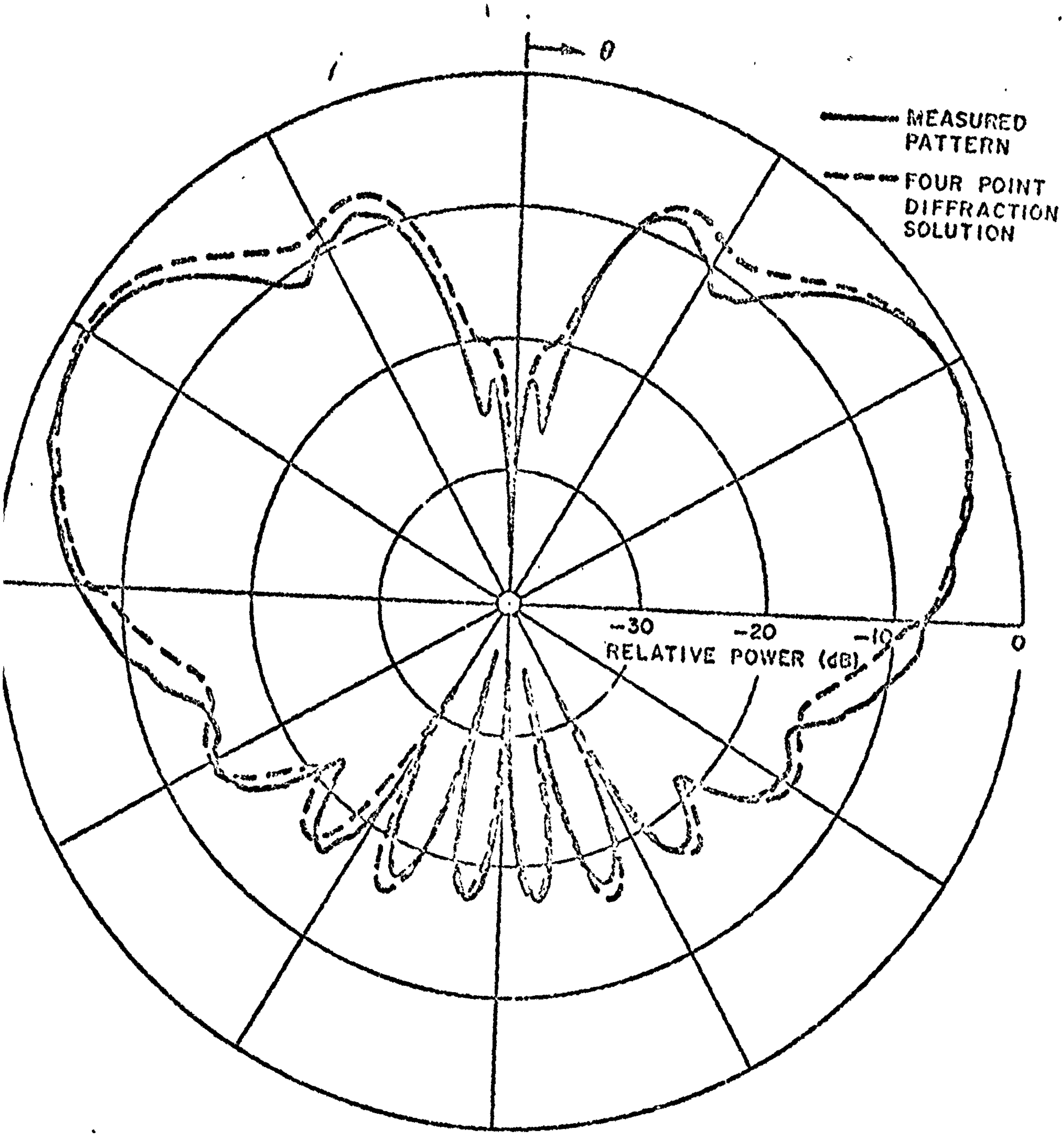



Fig. 5(c). E-theta radiation pattern for the x-z plane for the configuration in Fig. 5(a).

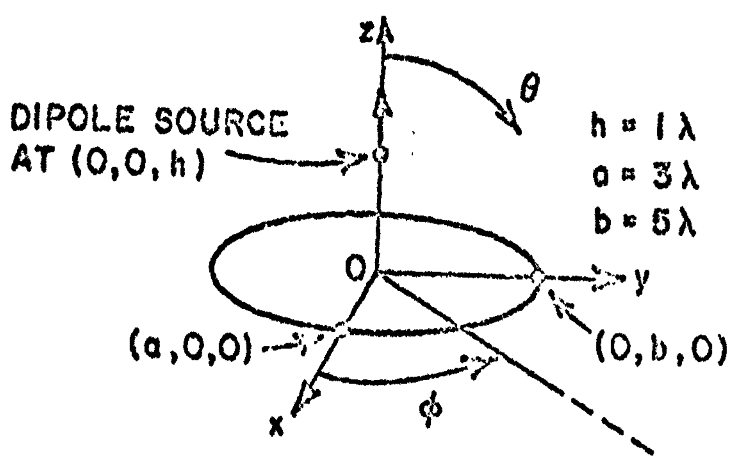



Fig. 6(a). Dipole off an elliptic disc.

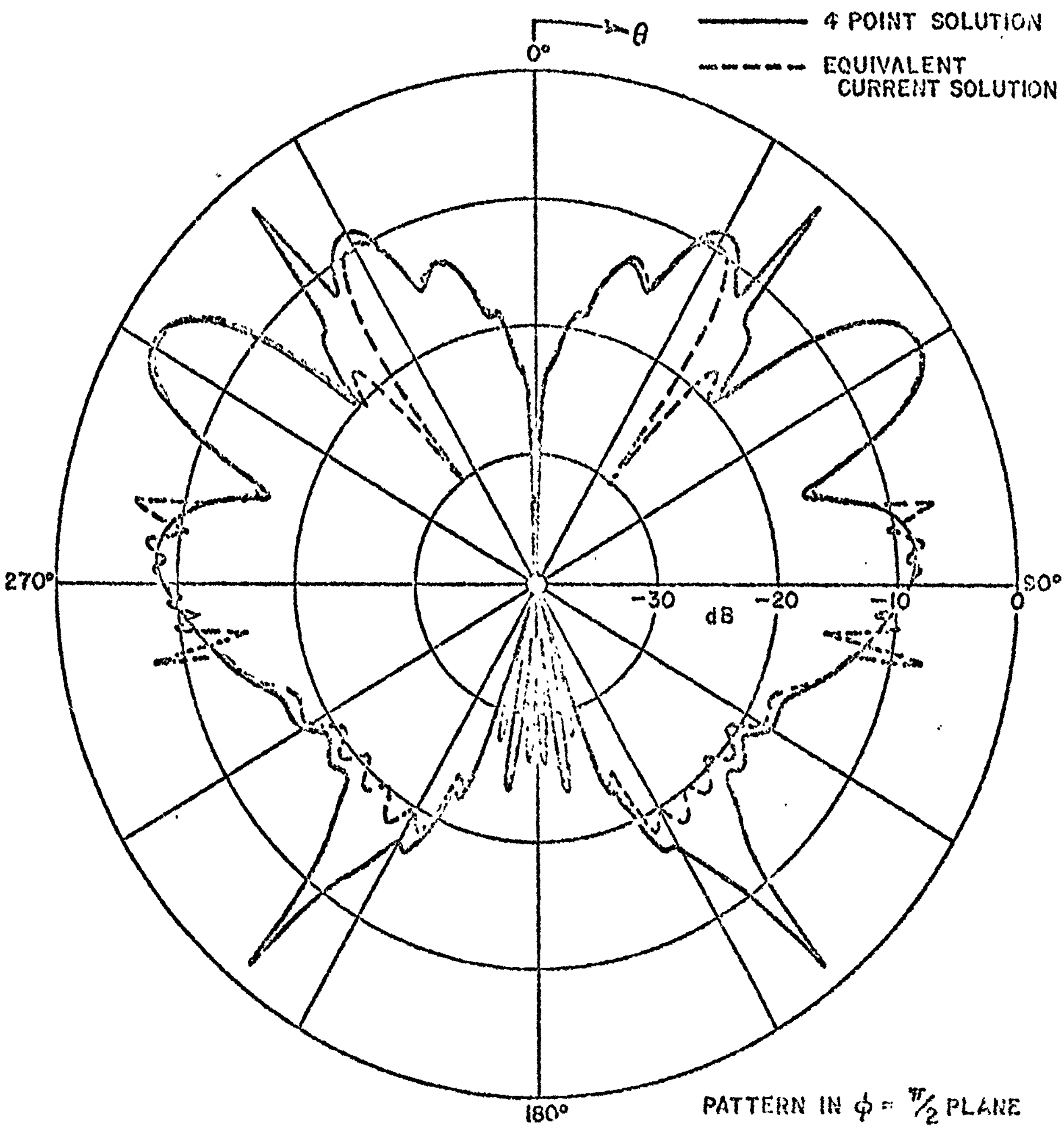



Fig. 6(b). Radiation pattern of the configuration in Fig. 6(a); the sharp peaks in the 4-point solution occur at the pseudo-caustics where the equivalent current solution must be employed.

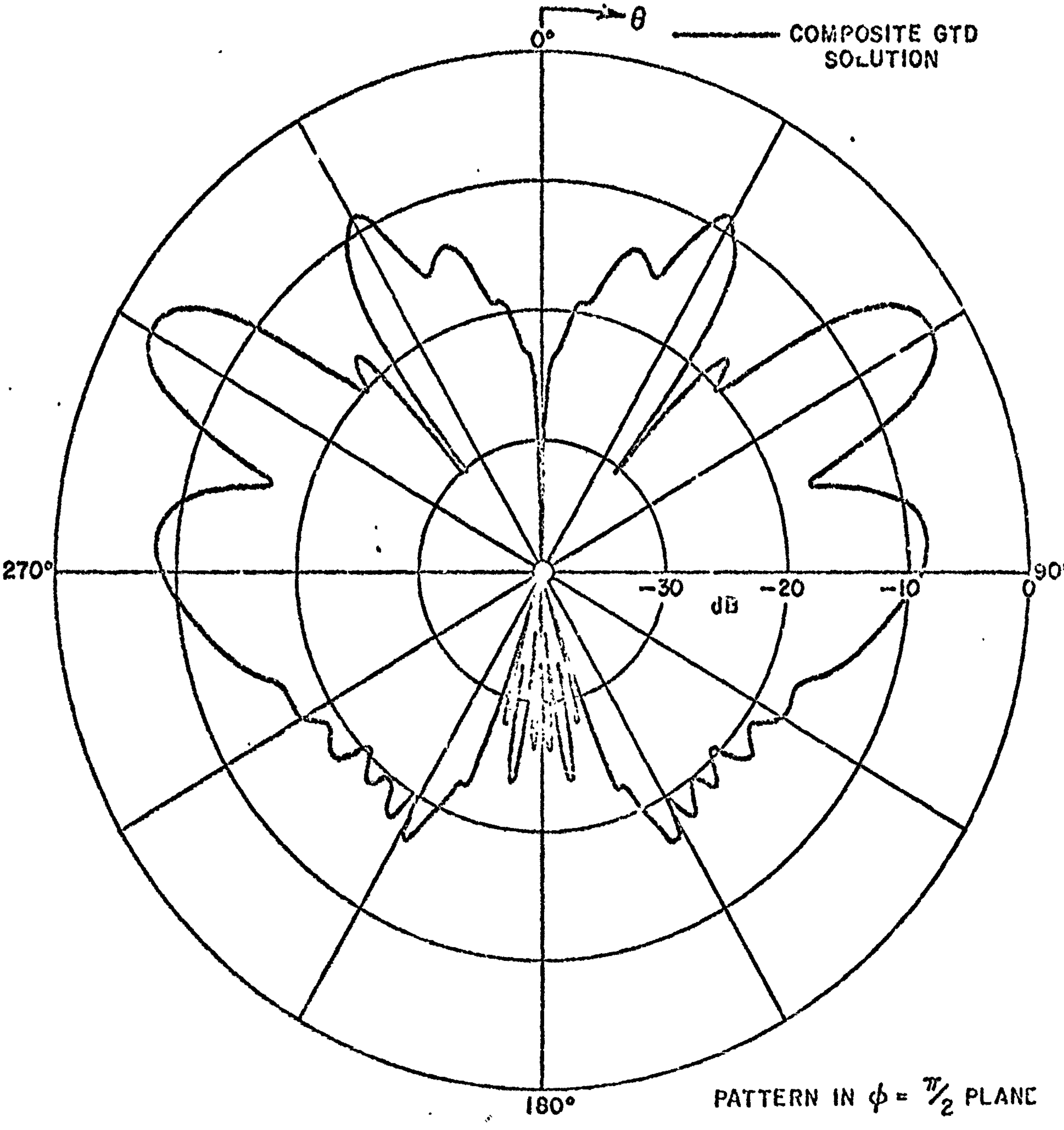



Fig. 6(c). The composite 4-point + equivalent current solution corresponding to Fig. 6(b).

these transition regions may extend over a significant angular region depending on the size of the cylinder and the source location.

Clearly, this study demonstrates the ability to predict cylinder shadowing effects, and the ripple effects in the pattern due to reflections off the fuselage for the line of sight (illuminated) region. If this model is used to analyze airborne antennas, the effects of the fuselage would probably most seriously affect low gain beacon type (tail-mounted) aircraft antennas. Also, the location of wing-mounted antennas can be chosen to minimize unwanted fuselage effects using our analysis.

## IV. PROPOSED FUTURE WORK

The following items are proposed as an extension to the present study.

(1) To generate a user-oriented computer code manual which would allow the user to realize the full potential and capability of the code in a simple and efficient manner.

(2) To further verify the accuracy of some of the analytical results via scattering measurements on the finite length circular and elliptic cylinders.

(3) To look into more efficient ways to decide the switching from the equivalent current method to the GTD four point solution for the rays diffracted from the elliptic edges of the end caps of the finite length elliptic cylinder. (See Section II B dealing with pseudo-caustic analysis.) This would involve the development of a uniform solution which remains valid in the pseudo-caustic region, but which also reduces to the GTD four point solution outside this region.

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